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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Process for Controlling an Installation for Plasma Treatment of Workpieces

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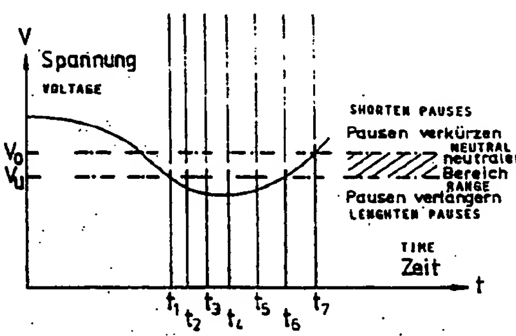
(54) Title: PROCESS FOR CONTROLLING AN INSTALLATION FOR PLASMA TREATMENT OF WORPIECES

(54) Bezeichnung: VERFAHREN ZUR STEUERUNG EINER ANLAGE ZUR PLASMABEHANDLUNG VON WERKSTÜCKEN



(57) Abstract

The invention relates to a process for controlling an installation for plasma treatment of workpieces. The installation has a constant voltage source for producing a glow discharge voltage V, which includes a control unit for controlling the magnitude of the glow discharge voltage V and a switch unit which can periodically switch off the glow discharge voltage V in various pulse-pause ratios. The installation also has a sensor for measuring the temperature of the workpiece, which is connected to the control unit so that the glow discharge voltage V is increased if the measured temperature is less than a given treatment temperature and decreased if the measured temperature is greater than the treatment temperature. The glow discharge voltage V is monitored so that if it falls below a lower threshold value the pulse-pause ratio of the glow discharge voltage V is reduced and if it exceeds an upper threshold value the pulse-pause ratio is increased.

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(57) Zusammenfassung

Bei dem Verfahren zur Steuerung einer Anlage zur Plasmabehandlung von Werkstücken weist die Anlage eine Gleichspannungsquelle für die Erzeugung einer Glimmentladungsspannung V auf, die einerseits eine Regeleinheit zur Regelung der Höhe der Glimmentladungsspannung V und andererseits eine Schalteinheit umfasst, durch welche die Glimmentladungsspannung V in unterschiedlichen Puls-Pausen-Verältnissen periodisch unterbrochen werden kann. Weiterhin hat die Anlage einen die Temperatur der Werkstücke erfassenden Sensor, der mit der Regeleinheit so verbunden ist, dass die Glimmentladungsspannung V hochgeregelt wird, wenn der erfasste Temperaturwert unterhalb einer vorgegebenen Behandlungstemperatur liegt und erniedrigt wird, wenn der erfasste Temperaturwert über der Behandlungstemperatur liegt. Die Glimmentladungsspannung V wird dergestalt überwacht, das bei Unterschreiten eines unteren Schwellenwertes das Puls-Pausen-Verhältnis der Glimmentladungsspannung V verringert wird. Bei Überschreiten eines oberen Schwellenwertes wird das Puls-Pausen-Verhältnis vergrössert.

Title: Method for Controlling a System for the Plasma Treatment of Workpieces

The invention pertains to a method for controlling a system for the plasma treatment of workpieces, especially a system for plasma nitriding.

A method of this type is already known from German Patent 1 058 806, which goes back to the legal predecessor of the applicant, in which the temperature of workpieces in a discharge vessel is detected by a pyrometer serving as a sensor, and the test voltage picked up at the pyrometer, which is proportional to the temperature, is used to regulate the level of the glow-discharge voltage. The gas pressure in the system is also varied to control the electrical glow discharge in this previously known method.

German Patent 904 491, which goes back to the same owner, describes a method for controlling a plasma treatment, in which the gas discharge is designed to occur discontinuously by, among other means, influencing an electrical determinant. The gas discharge then no longer acts continuously, as was formerly customary, but rather in the form of pulses, whose durations relative to the pause intervals are adjusted in such a way that the mean value of the supplied energy, taking into consideration the intensity of the pulses, gives the desired temperature values of the treatment temperature.

To be sure, cycling or pulsing of the discharge process provides an additional means of controlling the plasma treatment (in addition to regulation of discharge voltage). However, this does not solve the problem of how one can actually adjust the voltage and pulse-pause ratio in concrete cases of workpiece treatment. In particular, there is no indication as to how the two parameters can be adjusted relative to each other to achieve the best possible plasma treatment results.

The goal of the invention was to develop a method for controlling a system for the plasma treatment of workpieces, which would allow automatic adjustment and thus an automated operation.

Starting from the previously known method for controlling a system for the plasma treatment of workpieces, especially a plasma nitriding system, this goal is achieved by the features of Patent Claim 1.

The specific selection of the controlled quantities and the type of control allow for very effective influence on the course of the plasma treatment and at the same time allow a simple control sequence. The operation of the system is greatly simplified overall. In accordance with the invention, the peak value of the glow-discharge voltage is monitored and compared with a suitable predetermined lower threshold value, which is selected in such a way that significant glow problems do not yet appear at this value. If, starting from a higher glow-discharge voltage, the lower threshold value is reached, either cycling of the glow-discharge voltage is initiated with a certain time delay (but then a large pulse and a small pause component is used, e.g., 90 : 10), or, if the system is already operating in a cycled operation, a switch is made to a pulse-pause ratio with a higher pause component.

This switch reduces the average power applied to the surface of the workpiece. This in turn lowers the workpiece temperature. However, since this is automatically controlled by the power supplied to the surface of the workpiece, the temperature regulator increases the glow-discharge voltage in the pulse times, which is also accompanied by an increase in the pulse current. As a result, the temperature of the workpiece rises again.

If the glow-discharge voltage (during the pulse times) continues to remain below the lower threshold value, the next pulse level with a still higher pause component cuts in after a certain time delay. This continues until either a preset end level of the pulse-pause ratio is reached or the glow-discharge voltage exceeds the lower threshold value.

If a second, higher threshold value is then exceeded, the pulse levels are slowly switched back again until the peak voltage remains between the lower and the upper threshold value. If the pulse current reaches the nominal current of the electric system at pulses that are too short and pauses that are too long, the pulses are automatically lengthened again, so that the pulse current is automatically reduced by the temperature regulator.

Automatic operation of a plasma treatment can be achieved in this way. Automatic control of this kind is especially important for large batches, in which the mean glow-discharge voltage is small due to the mutual heating, or for thermally insulated containers. In such batches, if a high pressure must be used because of the geometry of the workpieces, glow problems can easily arise, with the result that the surfaces are not hardened or are only incompletely hardened. The method of the invention allows an optimal course of the plasma treatment even in cases such as these.

The control method of the invention is especially important for regulating the equilibrium state during a plasma treatment, i.e., when the charge has already been heated and is now near the desired treatment temperature.

In a preferred modification of the method of the invention, it is proposed that the glow-discharge voltage first be applied continuously or at least quasi-continuously at the beginning of a plasma treatment, and that the pulse steps be switched on only later. In this way, the workpiece heating process is accelerated, and thus the total time of the plasma treatment is shortened.

It is also advantageous if, at the beginning of the plasma treatment, the glow-discharge voltage is monitored only towards its lower threshold value. Monitoring of the upper threshold value becomes necessary only after the glow-discharge voltage has fallen below the lower threshold value and then rises again to exceed the upper threshold value.

In an advantageous modification, voltage control by the control unit takes precedence over adjustment of the pulse-pause ratio. Accordingly, the pulse-pause ratio is not changed until the possibilities of exclusive voltage regulation have been exhausted.

In accordance with the invention, it is also advantageous to adjust the pulse-pause ratio of the individual pulse steps in discrete values. Continuous adjustment of the pulse-pause ratio is basically possible, but control in discrete steps is more easily realized and leads to more stable control circuits.

The method of the invention can be used both for pulse systems with pulse-pause ratios in the microsecond range and for slowly, intermittently operated (cycled) direct-current systems. It is basically independent of the selected duration of a work cycle.

The time constant, after which a change is made in the pulse-pause ratio, is preferably selected greater than the duration of a few periods of the pulse-cycle ratio. This prevents short-term disturbances from causing a switch to other pulse steps when such a switch is not yet necessary in accordance with the process.

The sequence of the method of the invention will now be explained in greater detail with reference to two graphs.

Figure 1 is a graph of the electric power P as a function of time.

Figure 2 is a corresponding graph of the glow-discharge voltage V as a function of time with the same time intervals as Figure 1.

The left side of the graphs, i.e., at low time values, shows the heating process for a charge. A high electric power P is required for the heating process. The electric power P decreases as the temperature of the workpieces approaches the treatment temperature. Accordingly, the power curve and thus the curve of the glow-discharge voltage V decrease. During this period, the glow-discharge voltage V falls to values below the lower threshold value V_u. At a glow-discharge voltage V below V_u, sufficient glow treatment of the entire surface of the workpiece is no longer guaranteed. The system automatically switches to pulse operation. In the first pulse step the pulse-pause ratio is still not very pronounced. Accordingly, the power P shows an instantaneous abrupt drop when the first pulse step is switched on at time t_1, but the magnitude of this drop is small. Then, since the electric power P applied in the unit of time is smaller, the workpiece temperature drops, and this is counteracted by increasing the glow-discharge voltage V. In the graph in Figure 2, this manifests itself as a less steep decline, and

the curve of glow-discharge voltage V as a function of time passes through a point of inflection. Since the glow-discharge voltage V continues to stay below the lower threshold value V_u, the next pulse step is switched on at time t_2 after a certain delay. At time t_2 the pulse-pause ratio is 80 : 20. In the electric power graph in Figure 1, this takes the form of a larger abrupt drop at time t_2. In the voltage graph in Figure 2, the curve becomes even flatter.

However, the glow-discharge voltage V is still below the lower threshold value. Therefore, the third pulse step is switched on at time t_3. In the electric power graph in Figure 1, we again observe an abrupt drop in power, but this is now followed by a steeper increase in the power P.

These steps continue until, at a predetermined pulse step (in the example under consideration here, in the fifth pulse step at time t_4), the lower threshold value V_u is exceeded again. As long as the glow-discharge voltage V is below the lower threshold value V_u, the switching unit of the voltage supply receives the instruction to increase the pauses (region "lengthen pauses"). Above the lower threshold value V_u there is a "neutral region," which should be reached and maintained. It is limited on the upper side by the upper threshold value V_o, above which the region "shorten pauses" is located. In the specific example shown here, the glow-discharge voltage V exceeds the upper threshold value V_o at time t_7, and after time t_7 it rises to values above the upper threshold value V_o. After the preset time delay, the switching unit then switches back to the fifth pulse step, which had previously been switched to between times t_5 and t_6.

The above-described sequence is continuously repeated to keep the value of the glow-discharge voltage V in the neutral region between the two threshold values V_u and V_o.

The graph in Figure 1 also shows the behavior of the power P without cycling (dotted line). In accordance with the invention, the solid line of the power curve approaches this dotted line from both sides. As a result of the cycling in accordance with the invention and the corresponding method for controlling the pulse steps, the solid curve comes closer and closer to the ideal power curve (dotted curve).

CLAIMS

1. Method for controlling a system for the plasma treatment of workpieces, especially a system for plasma nitriding, such that the system has

a) a direct-current source for producing a glow-discharge voltage V, which comprises a regulating unit for regulating the magnitude of the glow-discharge voltage V and a switching unit, by which the glow-discharge voltage V can be periodically interrupted in variable pulse-pause ratios, and

b) a sensor for detecting the temperature of the workpieces, which sensor is connected with the regulating unit in such a way that the glow-discharge voltage V is regulated upward if the detected temperature value is below a predetermined treatment temperature and downward if the detected temperature value is above the treatment temperature, and

such that the glow-discharge voltage V is monitored in such a way that the pulse-pause ration is reduced when the glow-discharge voltage V falls below a lower threshold value of the glow-discharge voltage V and is increased when it rises above an upper threshold value of the glow-discharge voltage V.

2. Method in accordance with claim 1, characterized by the fact that, during the plasma treatment, the glow-discharge voltage V is first applied continuously or at least quasi-continuously (e.g., pulsation), and that cycling with a pulse-pause ratio occurs only after the voltage has fallen below the lower threshold value.

3. Method in accordance with claim 1, characterized by the fact that the glow-discharge voltage V is above the upper threshold value at the beginning of a plasma treatment.

4. Method in accordance with claim 1, characterized by the fact that, at the beginning of a plasma treatment, the pulse-pause ratio is increased only after the lower threshold value has been reached.

5. Method in accordance with claim 1, characterized by the fact that voltage control by the regulating unit has precedence over adjustment of the pulse-pause ration by the switching unit.

6. Method in accordance with claim 1, characterized by the fact that the pulse-pause ratio can be adjusted in several discrete steps, especially with the ratios 90:10, 80:20, 70:30 etc. to 10:90.

7. Method in accordance with claim 1, characterized by the fact that the time period of the pulse-pause ratio is in the range of microseconds to minutes.

8. Method in accordance with claim 1, characterized by the fact that a switch to a different pulse step (with a different pulse-pause ratio) is not made until the voltage has fallen below or risen above the predetermined threshold value V_u or V_o during a certain interval of time, which is at least a few cycle periods in length.

9. Method in accordance with claim 1, characterized by the fact that the treatment vessel is thermally insulated.

10. Method in accordance with claim 1, characterized by the fact that the pulse duration is automatically lengthened when, at pulses that are too short and pauses that are too long, the nominal current of the voltage source is reached during the pulses.

FIG. 1

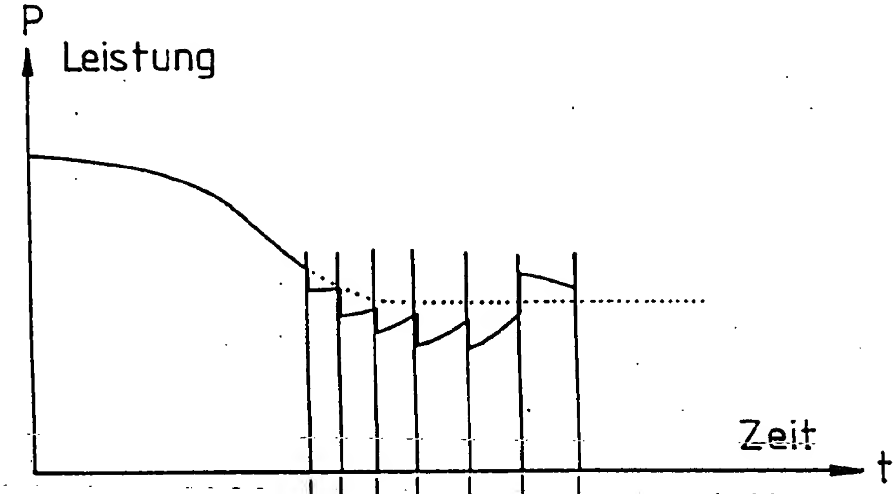
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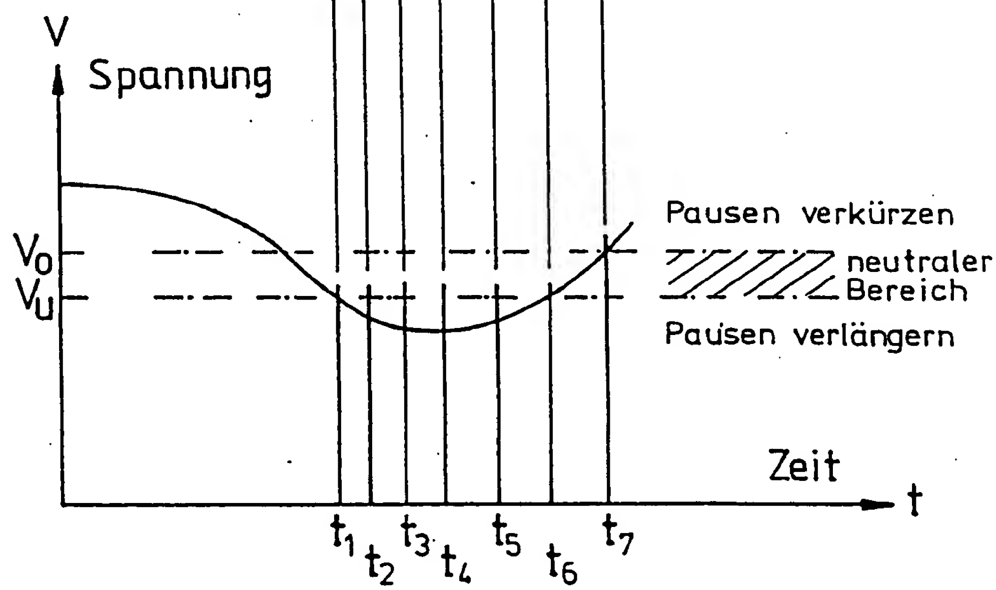
FIG. 2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